

APPLICATION FOR UNITED STATES LETTERS PATENT

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INVENTION:        DISPERSION MONITORING METHOD AND  
                     APPARATUS AND DISPERSION SLOPE  
                     TEMPERATURE DEPENDENCY COMPENSATION  
                     METHOD AND APPARATUS

S P E C I F I C A T I O N

This application claims priority from Japanese Patent Application No. 2002-214575 filed July 23, 2002, which is incorporated hereinto by reference.

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## BACKGROUND OF THE INVENTION

### FIELD OF THE INVENTION

The present invention relates to a dispersion  
10 monitoring method and apparatus as well as a dispersion  
slope temperature dependency compensation method and  
apparatus, more specifically, relates to a method of  
monitoring a dispersion variation amount on a transmission  
optical fiber in a wavelength division multiplexing (WDM)  
15 optical transmission system and a compensation method of  
a dispersion of a transmission line.

### DESCRIPTION OF THE RELATED ART

20 At present, research/development has been promoted  
on optical communication of high speed/large capacity for  
carrying a photonic network in the future. In realizing  
such an optical communication, there is compensation of  
a dispersion of a transmission line as one of important  
25 problems. As shown in Fig. 1, in an optical transmission  
system, an optical signal (A in the figure) generated from  
a transmitter 1 is transmitted to a transmission optical

fiber 2 and is transmitted to a receiver 5 while being optically amplified by optical repeaters 3 at certain distances. The optical signal immediately after transmission is deteriorated in a waveform thereof by  
5 dispersions of the transmission optical fiber 2 and the optical repeaters 3 (B in the figure). When the optical signal is directly received, an error is produced in reading the signal by interference between contiguous optical pulses. Further, the more increased the velocity  
10 of the optical signal, the more reduced the 1 time slot (time width occupied by 1 bit) and therefore, the more increased is the influence on a transmission characteristic by a dispersion D (ps/nm). Therefore, there is a demand for a dispersion compensation means 4  
15 for compensating the dispersion of the transmission line (transmission optical fiber and optical repeater).

What poses a problem here is that a dispersion of the transmission optical fiber is varied by temperature. In the case of a 1.3 $\mu$ m zero dispersion fiber (single mode  
20 fiber: SMF) or a dispersion-shifted fiber, it is known that the dispersion is changed by the following equation by shifting a zero dispersion wavelength by a temperature change  $\Delta T(\text{deg})$  (K.S. Kim and M.E. Lines, "Temperature dependence of chromatic dispersion in dispersion-shifted  
25 fibers: Experiment and analysis", J.Appl. Phys., Vol. 73, No. 5, pp.2069-2074, 1993).

$$\Delta D = Z \cdot S \cdot L \cdot \Delta T \quad (1)$$

where  $\Delta D(\text{ps/nm})$  designates a dispersion change amount,  
 $Z(\text{nm/deg})$  designates a temperature constant of zero  
dispersion wavelength shift,  $S(\text{ps/nm}^2/\text{km})$  designates a  
dispersion slope (wavelength differential of dispersion)  
5 and  $L(\text{km})$  designates an optical fiber length.

Heretofore, a variation amount of the dispersion by  
the temperature change has been regarded as constant  
without depending on the wavelength. Therefore,  
according to an adaptive dispersion equalization  
10 technology which has been proposed until present time, the  
variation of the dispersion is equalized among respective  
channels by the same amount (T. Inui et al. "Adaptive  
dispersion slope equalizer using a nonlinearly chirped  
fiber Bragg grating pair with a novel dispersion detection  
15 technique", IEEE Photon. Technol. Lett., vol. 14, no. 4,  
P. 549 (2002), H. Ooi et al., "40-Gbit/s WDM automatic  
dispersion compensation with virtually imaged phased  
array (VIPA) variable dispersion compensators", IEICE  
Trans. Commun., vol. E85-B, no. 2, p. 463 (2002)).

20 A reverse dispersion fiber (RDF) which has been  
developed recently (K. Mukasa et. al., "Novel network fiber  
to manage dispersion at  $1.55\ \mu\text{m}$  with combination of  $1.3\ \mu\text{m}$   
zero dispersion single mode fiber", ECOC'97, 1, p. 127  
(1997)) is a fiber in which a dispersion/a dispersion slope  
25 are provided with signs reverse to the sign of the  $1.3\ \mu\text{m}$   
zero dispersion optical fiber (single mode fiber: SMF) and  
absolute values thereof are near to those of SMF. By

combining RDF with SMF, a transmission line in which both of dispersion and dispersion slope are near to zero can be realized. Therefore, a transmission line combined with SMF and RDF is used in WDM transmission (K.Yonenaga et al.,  
5 "Dispersion-compensation-free 40 Gbit/s×4-channel WDM transmission experiment using zero-dispersion flattened transmission line", OFC'98, PD20 (1998), E. Yamada et al.,  
"106 channel×10 Gbit/s, 640 km DWDM transmission with 25 GHz spacing with supercontinuum multi-carrier source",  
10 Electron. Lett., vol. 37, p. 1534 (2001)), and in ultra high speed OTDM transmission (M. Nakazawa et al., "1.28 Tbit/s-70 km OTDM transmission using third- and fourth-order simultaneous dispersion compensation with a phase modulator", Electron Lett., vol. 36, p. 2027 (2000)).  
15 Further, RDF is utilized not simply as a transmission medium but a fiber for Raman amplification by utilizing the fact that a core diameter thereof is smaller than that of SMF or a dispersion-shifted fiber (H. Kawakami et al.,  
"Highly efficient distributed Raman amplification system  
20 in a zero-dispersion flattened transmission line", OA&A'99, ThB5 (1999), E. Yamada et al., "106 channel×10 Gbit/s, 640 km DWDM transmission with 25 GHz spacing with supercontinuum multi-carrier source", Electron Lett., vol. 37, p. 1534 (2001)).

25       Although it has been known that the dispersion of the optical fiber is provided with temperature dependency, the temperature dependency of the dispersion slope has not been

investigated. However, it has been known that a fiber having negative dispersion/dispersion slope as in RDF is provided with temperature dependency of the dispersion slope, that is, the wavelength dependency of the temperature dependency of the dispersion which cannot be disregarded. When a high speed/wide bandwidth WDM transmission line is constructed by SMF and RDF without taking the characteristic into consideration, a dispersion having a different value among channels is produced by temperature change exceeding an allowable dispersion value depending on channels.

<Temperature dependency of dispersion slope of RDF>

Fig. 2A and Fig. 2B schematically show respective dispersion curves (dispersion vs wavelength) of SMF and RDF. In the case of the fiber having a negative dispersion slope of a dispersion as in RDF, structural dispersion is adjusted by devising a refractive index profile and dispersion on a side of a long wavelength is increased in a negative direction. Therefore, when dispersion vs wavelength of the fiber is plotted, whereas dispersion vs wavelength of SMF substantially becomes a linear line, that of RDF becomes a line having a radius of curvature. This can be expressed also as an absolute value of a quartic dispersion (wavelength differential of dispersion slope) is larger than that of SMF.

In this case, when changes of dispersions at wavelengths  $\lambda_1$  and  $\lambda_2$  in the case of changing temperature

of the fiber from  $T_1$  to  $T_2$  are observed, when the dispersion curves are shifted by temperature change, in the case of SMF of Fig. 2A, magnitudes of change amounts  $\Delta D_{1SMF}$  and  $\Delta D_{2SMF}$  at  $\lambda_1$  and  $\lambda_2$  are almost the same. In contrast thereto, in  
5 the case of a fiber having a dispersion characteristic having a radius of curvature as in RDF, as shown in Fig. 2B, magnitudes of change amounts  $\Delta D_{1RDF}$  and  $\Delta D_{2RDF}$  at  $\lambda_1$  and  $\lambda_2$  are clearly different from each other. The fact represents that the wavelength dependency which cannot be  
10 disregarded is present in the temperature dependency of the dispersion of RDF (the fact may be regarded as the dispersion slope of RDF is provided with temperature dependency).

Fig. 3 shows curves produced by measuring temperature  
15 dependency constants of dispersions with regard to SMF and RDF and the temperature dependency constants are plotted with respect to four wavelengths. An inclination of a liner line produced by connecting the four points becomes equivalent to temperature dependency constants of the  
20 dispersion slopes. Whereas the value is  $1.79 \times 10^{-6} \text{ps/km/nm}^2/\text{deg}$  for SMF, the value for RDF is  $1.48 \times 10^{-5} \text{ps/km/nm}^2/\text{deg}$  which is larger than the value of SMF by one order of magnitude.

<Influence effected by temperature dependency of  
25 dispersion slope>

When a wavelength bandwidth of an optical signal in an optical transmission system is defined as  $\Delta\lambda(\text{nm})$  and

a temperature dependency constant and a length of a dispersion slope of a transmission optical fiber are defined respectively as  $\alpha_T$ (ps/nm<sup>2</sup>/km/deg) and L(km) and a temperature variation is defined as  $\Delta T$ (deg), a dispersion change amount difference  $\Delta D$ (ps/nm) is represented by the following equation.

$$\Delta D = \alpha_T \cdot L \cdot \Delta T \cdot \Delta \lambda \quad (2)$$

Therefore, for example, when a transmission line is provided with a value  $\alpha_T = 1.48 \times 10^{-5}$  (ps/nm<sup>2</sup>/km/deg) similar to that of RDF and the optical fiber length is set to L=1000(km), the temperature change is set to  $\Delta T = 50$ (deg) and the wavelength bandwidth is set to  $\Delta \lambda = 100$ (nm), the dispersion change amount difference becomes  $\Delta D = 62.5$ (ps/nm). That is, even when the dispersion is set to 0 in a total range of the wavelength bandwidth of 100nm at an initial time of operating a WDM transmission system and a variation amount of the dispersion is compensated by an adaptive type dispersion equalizer by the same amount over a total wavelength bandwidth, by the temperature dependency of the dispersion slope, a difference of a dispersion of 62.5(ps/nm) is produced between channels of the shortest wavelength and the longest wavelength. In this case, application to a WDM transmission system (allowable dispersion of about 40ps/nm) of 40Gbit/s/ch becomes difficult.

As described above, a dispersion of a value which differs among channels is produced by a temperature change



in WDM transmission of high speed/wide bandwidth by the temperature dependency of the dispersion slope provided to the optical fiber. Therefore, even when the variation amount of the dispersion is compensated by the adaptive  
5 type dispersion equalizer by the same amount over a total wavelength bandwidth, there poses a problem that the variation amount exceeds the allowable dispersion value depending on channels.

## 10 SUMMARY OF THE INVENTION

It is an object of the invention to monitor and compensate a wavelength dependency of a temperature dependency of a dispersion, in other words, a temperature  
15 dependency of a dispersion slope in a WDM optical transmission system.

According to a first aspect of the invention, in a dispersion monitoring method according to the invention, there is provided a method of monitoring a dispersion on  
20 a transmission optical fiber in a wavelength division multiplexing optical transmission system, the method comprising the steps of extracting two or more of wavelength channels 1 to n from the transmission optical fiber and monitoring dispersions of the extracted  
25 wavelength channels.

Here, the step of monitoring the dispersions can include the steps of measuring a first dispersion value

in the extracted wavelength channels 1 to n  
(wavelength:  $\lambda_{mon1}$  to  $\lambda_{monn}$ ) at a certain temperature  $T_1(^{\circ}C)$ ,  
measuring a second dispersion value in the wavelength  
channels 1 to n at a certain other temperature  $T_2(^{\circ}C)$ ,  
5 providing dispersion variation amounts  $\Delta D_{mon1}$  to  $\Delta D_{monn}$  in  
the extracted wavelength channels 1 to n from a difference  
between the measured first dispersion value and the  
measured second dispersion value, and a step of providing  
a dispersion variation amount at an arbitrary wavelength  
10 ( $\lambda$ ) based on the provided dispersion variation amounts  
 $\Delta D_{mon1}$  to  $\Delta D_{monn}$ .

Here, the n may be 2 and the step of providing the  
dispersion variation amount can calculate a dispersion  
variation amount  $\Delta D(\lambda)$  in an arbitrary wavelength ( $\lambda$ ) by  
15 the following equation.

$$\Delta D(\lambda) = \frac{\Delta D_{mon2} - \Delta D_{mon1}}{\lambda_{mon2} - \lambda_{mon1}} \cdot (\lambda - \lambda_{mon1}) + \Delta D_{mon1}$$

Further, the step of monitoring the dispersions can  
include the steps of measuring a first dispersion value  
in a desired wavelength channel at a certain temperature  
20  $T_1(^{\circ}C)$ , measuring a second dispersion value in the desired  
wavelength channel at a certain other temperature  $T_2(^{\circ}C)$ ,  
and a step of providing a dispersion variation amount in  
the desired wavelength channel from a difference between  
the measured first dispersion and the measured second  
25 dispersion value.

According to a second aspect of the invention, in a

dispersion slope temperature dependency compensating method according to the invention, there is provided a method of compensating a temperature dependency of a dispersion slope in a wavelength division multiplexing optical transmission system, the method comprising the steps of providing the dispersion variation amount  $\Delta D(\lambda)$  by the above-described method and compensating the temperature dependency of the dispersion slope by using the provided dispersion variation amount  $\Delta D(\lambda)$ .

Here, the step of compensating the temperature dependency of the dispersion slope can include the steps of dividing a signal light on the transmission optical fiber to one or more wavelength channel groups constituted by at least one wavelength channel, and compensating the dispersion in accordance with each of the divided one or more wavelength channel groups.

Further, the step of compensating the dispersion can be carried out by using one or more tunable dispersion equalizers with a fiber Bragg grating.

Further, the step of compensating the dispersion can be carried out by using one or more tunable dispersion equalizers with a filter.

Further, the step of compensating the temperature dependency of the dispersion slope can summarizingly compensate a wavelength dependency of the temperature dependency of the dispersion in all of bandwidths in a wavelength division multiplexing optical transmission

system.

Further, the step of compensating the temperature dependency of the dispersion slope can be carried out by using one or more tunable dispersion equalizers with a  
5 fiber Bragg grating.

Further, the step of compensating the temperature dependency of the dispersion slope can include the step of providing a temperature change in a dispersion compensating optical fiber installed at an optical node.

10 According to a third aspect of the invention, in a dispersion monitoring apparatus according to the invention, there is provided a dispersion monitoring apparatus for monitoring a dispersion on a transmission optical fiber in a wavelength division multiplexing  
15 optical transmission system, the dispersion monitoring apparatus comprising extracting means for extracting two or more of wavelength channels from the transmission optical fiber and monitoring means for monitoring dispersions of the extracted wavelength channels.

20 According to a fourth aspect of the invention, in a dispersion slope temperature dependency compensating apparatus according to the invention, there is provided a dispersion slope temperature dependency compensating apparatus for compensating a temperature dependency of a  
25 dispersion slope in a wavelength division multiplexing optical transmission system, the dispersion slope temperature dependency compensating apparatus comprising

monitoring means for monitoring dispersions of two or more of wavelength channels on a transmission optical fiber, and compensating means for compensating a wavelength dependency of the temperature dependency of the dispersion  
5 in an arbitrary wavelength channel by using the monitored dispersions.

Here, the compensating means can include means for dividing a signal light on the transmission optical fiber into one or more wavelength channel groups constituted by  
10 at least one wavelength channel, and means for compensating the dispersion in accordance with each of the divided one or more wavelength channel groups.

Further, the compensating means can include one or more tunable dispersion equalizers with a fiber Bragg  
15 grating.

Further, the compensating means can include one or more tunable dispersion equalizers with a filter.

Further, the compensating means can summarizingly compensate the wavelength dependency of the temperature  
20 dependency of the dispersion in all of bandwidths in a wavelength division multiplexing optical transmission system.

Further, the compensating means can include one or more tunable equalizers with a fiber Bragg grating.

25 Further, the compensating means can include a dispersion compensating optical fiber installed in an optical node, and means for providing a temperature change

to the dispersion compensating optical fiber.

According to the invention, a wavelength division multiplexing optical transmission system without a deterioration in a transmission characteristic by an influence of a temperature dependency of a dispersion slope  
5 can be realized.

The above and other objects, effects, features and advantages of the present invention will become more apparent from the following description of embodiments  
10 thereof taken in conjunction with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

15 Fig. 1 illustrates an outline view of an optical transmission system;

Fig. 2A and Fig. 2B illustrate schematic views showing temperature dependencies of wavelength dependencies of dispersions of SMF and RDF;

20 Fig. 3 illustrates a diagram showing wavelength dependencies of temperature dependency constants of dispersions of SMF and RDF;

Fig. 4 illustrates a view showing an exemplified apparatus constitution of a dispersion slope temperature  
25 dependency compensating apparatus;

Fig. 5 illustrates a diagram showing a method of calculating a dispersion variation amount at a certain

wavelength;

Fig. 6 illustrates a view showing an apparatus constitution of a dispersion monitoring apparatus according to a first embodiment of the invention;

5        Fig. 7 illustrates a view showing an apparatus constitution of a dispersion slope temperature dependency compensating apparatus according to a fourth embodiment of the invention;

10       Fig. 8 illustrates a diagram for explaining an individual dispersion compensating method of respective channels;

15       Fig. 9 illustrates a view showing an apparatus constitution of a dispersion slope temperature dependency compensating apparatus according to an eighth embodiment of the invention;

Fig. 10 illustrates a diagram for explaining a summarizingly dispersion compensating method of all of bandwidths;

20       Fig. 11 illustrates a view of a tunable dispersion equalizer with a fiber Bragg grating capable of providing a temperature gradient in a longitudinal direction;

Fig. 12 illustrates a view of a tunable dispersion equalizer with a fiber Bragg grating capable of providing a strain distribution in a longitudinal direction; and

25       Fig. 13 illustrates a view showing a constitution of a dispersion slope temperature dependency compensating method according to a tenth embodiment of the invention.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 4 shows an apparatus constitution of a  
5 dispersion slope temperature dependency compensating  
apparatus for monitoring and compensating a dispersion  
variation amount of a transmission optical fiber in a WDM  
optical transmission system. Here, as a means for  
realizing a dispersion variation amount monitoring method,  
10 there is used a dispersion detection apparatus described  
in, for example, Japanese Patent Application No.  
2002-164437, U.S. Patent Application Publication No.  
US2003/0086713 A1, EU Patent Application Publication No.  
1309115 and T. Inui, K.R. Tamura, K. Mori and T. Morioka,  
15 "Bit rate flexible chirp measurement technique using  
two-photon absorption", Electronics Letters, vol. 38, no.  
23, 7th November 2002.

The dispersion slope temperature dependency  
compensating apparatus includes a dispersion detection  
20 apparatus and a tunable dispersion equalizer 406. The  
dispersion detection apparatus includes a wavelength  
tunable filter 408, an optical coupler 409, dispersive  
media 410 and 412, nonlinear photo-detecting means 414,  
a difference signal outputting means 416 and a controller  
25 404. The wavelength tunable filter 408 is constituted to  
be able to set a wavelength of light to be picked up. The  
dispersion media 410 and 412 use media having the same



absolute value D of a dispersion value and signs different from each other. The nonlinear photo-detecting means 414 outputs a voltage in proportion to a square of an intensity of light. The difference signal outputting means 416  
5 detects a difference between output voltages of the nonlinear photo-detecting means 414 and outputs a difference signal (voltage difference).

In order to know an influence amount of temperature dependency of a dispersion slope, dispersion variations  
10 of two channels are monitored. For example, by controlling the wavelength tunable filter 408 by the controller 404 comprising PC (personal computer) of the dispersion detection apparatus while setting a center wavelength thereof to extract a monitor channel 1( $\lambda_{\text{mon1}}$ ),  
15 a dispersion value in  $\lambda_{\text{mon1}}$  at a certain temperature  $T_1(^{\circ}\text{C})$  is measured. Light having a wavelength  $\lambda_{\text{mon1}}$  which has passed the wavelength tunable filter 408 is branched at the optical coupler 409 and inputted to the dispersion media 410 and 412. Light which has passed the dispersion  
20 medium 410 is broadened in a pulse width thereof, light which has passed the dispersion medium 412 is reduced in a pulse width thereof and these are inputted to the nonlinear photo-detecting means 414. The difference signal outputting means 416 calculates a dispersion value  
25 from a difference between outputs of the two nonlinear photo-detecting means 414 and stores the dispersion value to the controller 404.

Similarly, the center wavelength of the wavelength tunable filter 408 is set to extract a monitor channel 2 ( $\lambda_{\text{mon2}}$ ), a dispersion value in  $\lambda_{\text{mon2}}$  at  $T_1(^{\circ}\text{C})$  is measured and the dispersion value is stored to the controller 404.

5        Next, the dispersion detection apparatus measures a dispersion value in  $\lambda_{\text{mon1}}$  when there is a change in environment (temperature change) to change from the temperature  $T_1(^{\circ}\text{C})$  to a certain temperature  $T_2(^{\circ}\text{C})$ , and outputs the dispersion value to the controller 404. The  
10       controller 404 calculates a difference between the dispersion value in  $\lambda_{\text{mon1}}$  at temperature  $T_1(^{\circ}\text{C})$  and the dispersion value in  $\lambda_{\text{mon1}}$  at  $T_2(^{\circ}\text{C})$  to provide a dispersion variation amount  $\Delta D_{\text{mon1}}$ .

      Similarly, measurement of a dispersion value  $T_2(^{\circ}\text{C})$   
15       in  $\lambda_{\text{mon2}}$  is carried out. Then, a dispersion variation amount  $\Delta D_{\text{mon2}}$  in  $\lambda_{\text{mon2}}$  is derived from a difference between the dispersion value at temperature  $T_2(^{\circ}\text{C})$  and the dispersion value at temperature  $T_1(^{\circ}\text{C})$ .

      As shown in Fig. 5, when the dispersion variation  
20       amount at the monitor channel 1( $\lambda_{\text{mon1}}$ ) is  $\Delta D_{\text{mon1}}$  and the dispersion variation amount at the monitor channel 2( $\lambda_{\text{mon2}}$ ) is  $\Delta D_{\text{mon2}}$ , a dispersion variation amount  $\Delta D(\lambda)$  in an arbitrary wavelength  $\lambda$  is estimated as follows. (the dispersion variation amount  $\Delta D(\lambda)$  is approximated to a  
25       linear line since linearity of dispersion slope temperature dependency of RDF is highly excellent as indicated by  $R=0.99988$ ).

$$\Delta D(\lambda) = \frac{\Delta D_{mon2} - \Delta D_{mon1}}{\lambda_{mon2} - \lambda_{mon1}} \cdot (\lambda - \lambda_{mon1}) + \Delta D_{mon1} \quad (3)$$

From a result of the calculation, adaptive dispersion equalization is carried out by controlling the tunable dispersion equalizer 406 by the controller 404 to provide  
 5 an appropriate dispersion compensation amount in WDM channel.

When the dispersion is monitored more finely, or when the dispersion slope temperature dependency of the transmission optical fiber cannot be approximated by a  
 10 linear line, there may be constructed a constitution in which the dispersion is monitored in wavelength channels of a number larger than two and appropriate dispersion compensation amounts are provided to respective channels.  
 (First Embodiment)

15 Fig. 6 shows a first embodiment of the invention. In a transmission line in which a transmission optical fiber of a wavelength division multiplexing optical transmission system having a transmission rate of 40 Gbit/s is constituted by SMF and RDF, there is constructed a  
 20 constitution of using a dispersion detection apparatus described as a dispersion variation amount monitoring method in T. Inui, K.R. Tamura, K. Mori and T. Morioka, "Bit rate flexible chirp measurement technique using two-photon absorption", Electronics Letters, vol. 38, no.  
 25 23, 7th November 2002. As dispersion media of a dispersion monitoring apparatus, SMF 610 having a dispersion value

of 40ps/nm and a dispersion compensating fiber (DCF) 612 having a dispersion value of -40ps/nm are used, and as nonlinear photo-detecting means, a silicon avalanche photodiode (Si-APD) 614 showing two-photon absorption at 1.5 $\mu$ m band is used. In order that dispersion values of the dispersion media are constant regardless of a wavelength, it is preferable that the optical fiber is of a dispersion flattened type. A cut-off frequency of Si-APD614 sufficiently smaller than the transmission rate is used. Thereby, direct current voltage can be provided as an output. For example, an Si-APD having a cut-off frequency of 10MHz is used relative to the transmission rate of 40Gbit/s. Here, fiber Bragg gratings can be utilized as dispersion media and SHG (second harmonic generation) crystals can be utilized as non linear photo-detecting means.

A differential amplifier 616 detects a difference between output voltages of Si-APDs 614 of the two paths and outputs a difference signal (voltage difference). The difference signal shows a value in accordance with a magnitude of the dispersion (chirp) and therefore, the difference signal can detect and measures the dispersion of the transmission optical fiber.

In order to measure temperature dependency of a dispersion slope of the transmission optical fiber, dispersion variations of two channels in a WDM signal are monitored. A wavelength tunable filter 608 is installed

before a branch to the two paths in the dispersion detection apparatus, the filter is controlled by a controller 604 comprising PC (personal computer) and a center wavelength thereof is set to extract a monitor channel 1 ( $\lambda_{\text{mon1}}$ ).  
5 Further, a dispersion value in  $\lambda_{\text{mon1}}$  at a certain temperature  $T_1(^{\circ}\text{C})$  is measured and the dispersion value is stored to the controller 604. Similarly, the center wavelength of the wavelength tunable filter is set to extract a monitor channel 2( $\lambda_{\text{mon2}}$ ), a dispersion value in  $\lambda_{\text{mon2}}$  at  $T_1(^{\circ}\text{C})$  is  
10 measured and the dispersion value is stored to the controller 604.

Next, a dispersion value in  $\lambda_{\text{mon1}}$  when there is a change in temperature to constitute a certain temperature  $T_2(^{\circ}\text{C})$  is measured and a dispersion variation amount  $\Delta D_{\text{mon1}}$  in  $\lambda_{\text{mon1}}$   
15 is derived from a difference from a dispersion value at temperature  $T_1(^{\circ}\text{C})$ . Similarly, measurement of a dispersion value at  $T_2(^{\circ}\text{C})$  in  $\lambda_{\text{mon2}}$  is carried out. Then, a dispersion variation amount  $\Delta D_{\text{mon2}}$  in  $\lambda_{\text{mon2}}$  is derived from a difference between the dispersion value at temperature  
20  $T_2(^{\circ}\text{C})$  and the dispersion value at temperature  $T_1(^{\circ}\text{C})$ .

When the dispersion slope temperature dependency of the transmission optical fiber can be approximated by a linear line, a dispersion variation amount  $\Delta D(\lambda)$  in a certain arbitrary wavelength ( $\lambda$ ) is represented as follows  
25 and therefore, the dispersion variation amounts, that is, dispersion amounts to be compensated in respective wavelength channels are known from the equation.

$$\Delta D(\lambda) = \frac{\Delta D_{mon2} - \Delta D_{mon1}}{\lambda_{mon2} - \lambda_{mon1}} \cdot (\lambda - \lambda_{mon1}) + \Delta D_{mon1} \quad (3)$$

(Second Embodiment)

In a transmission line in which a transmission optical fiber of a wavelength division multiplexing optical transmission system is constituted by SMF and RDF, there is constructed a constitution of using a dispersion detection apparatus described as a dispersion variation amount monitoring method in T. Inui, K.R. Tamura, K. Mori and T. Morioka, "Bit rate flexible chirp measurement technique using two-photon absorption", Electronic Letters, vol. 38, no. 23, 7th, November 2002, similar to the first embodiment shown in Fig. 6.

Center wavelengths of a wavelength tunable filter are set one by one for all of wavelength channels by the controller 604 comprising PC (personal computer) and dispersion values are monitored. For example, in a wavelength division multiplexing optical transmission system comprising 32 channels, dispersion values in wavelength channels 1 to 32 ( $\lambda_{mon1}$  to  $\lambda_{mon32}$ ) at a certain temperature  $T_1(^{\circ}\text{C})$  are measured and the dispersion values are stored to the controller 604. Next, by measuring dispersion values in  $\lambda_{mon1}$  to  $\lambda_{mon32}$  when a certain other temperature  $T_2(^{\circ}\text{C})$  is constituted, dispersion variation amounts  $\Delta D_{mon1}$  to  $\Delta D_{mon32}$  in all of the wavelength channels  $\lambda_{mon1}$  to  $\lambda_{mon32}$  can be monitored by differences from the dispersion values at temperature  $T_1(^{\circ}\text{C})$  for the respective

wavelength channels. By monitoring the dispersion variation amounts of the respective channels, appropriate dispersion compensation amounts in the respective channels can be known.

5 (Third Embodiment)

In a transmission line in which a transmission optical fiber of a wavelength division multiplexing optical transmission system is constituted by SMF and RDF, there is constructed a constitution of using a dispersion  
10 detecting apparatus described as a dispersion variation amount monitoring method in T. Inui, K.R. Tamura, K. Mori and T. Morioka, "Bit rate flexible chirp measurement technique using two-photon absorption", Electronics Letters, vol. 38, no. 23, 7th November 2002, similar to  
15 the first embodiment shown in Fig. 6.

Center wavelengths of a wavelength tunable filter are set one by one for a plurality of wavelength channels by the controller 604 comprising PC (personal computer) and dispersion values are monitored. For example, in a  
20 wavelength division multiplexing optical transmission system comprising 128 channels, dispersion values in monitor channels 1 to 32 ( $\lambda_{\text{mon}1}$  to  $\lambda_{\text{mon}32}$ ) at certain intervals (at intervals of 4 channels in this case) at a certain temperature  $T_1(^{\circ}\text{C})$  are measured and the dispersion values  
25 are stored to the controller 604. Next, by measuring dispersion values in  $\lambda_{\text{mon}1}$  to  $\lambda_{\text{mon}32}$  when a certain other temperature  $T_2(^{\circ}\text{C})$  is constituted, dispersion variation

amounts  $\Delta D_{\text{mon1}}$  to  $\Delta D_{\text{mon32}}$  in wavelength channels of  $\lambda_{\text{mon1}}$  to  $\lambda_{\text{mon32}}$  at intervals of 4 channels are monitored from differences from the dispersion values at temperature  $T_1(^{\circ}\text{C})$ . There is constructed a constitution of calculating  
5 a dispersion variation amount  $\Delta D(\lambda)$  at a certain arbitrary wavelength ( $\lambda$ ) by plotting values of the dispersion variation amounts on a graph and providing an approximated curve thereof by, for example, a least squares method.

The dispersion variation monitoring method can deal  
10 with also a case in which the dispersion slope temperature dependency of the transmission optical fiber cannot be approximated by a linear line.

(Fourth Embodiment)

Fig. 7 shows a fourth embodiment of the invention.  
15 In a 40Gbit/s WDM optical transmission system, in which a transmission optical fiber is constituted by SMF and RDF, there is constructed a constitution of using a dispersion detection apparatus described as a dispersion variation amount monitoring method in T. Inui, K.R. Tamura, K. Mori  
20 and T. Morioka, "Bit rate flexible chirp measurement technique using two-photon absorption", Electronics Letters, vol. 38, no. 23, 7th November 2002. As dispersion media of a dispersion monitoring apparatus, SMF 610 having a dispersion value of 40ps/nm and a dispersion compensating  
25 fiber (DCF) 612 having a dispersion value of -40ps/nm are used and as nonlinear photo-detecting means, a silicon avalanche photodiode (Si-APD) 614 showing two-photon



absorption at 1.5 $\mu$ m band is used. In order that dispersion values of the dispersion media are constant regardless of a wavelength, it is preferable that the optical fiber is of a dispersion flattened type. A cut-off frequency of Si-APD 614 sufficiently smaller than a transmission rate is used. Thereby, direct current voltage can be provided as an output. For example, Si-APD having a cut-off frequency of 10MHz is used relative to a transmission rate of 40Gbit/s.

The differential amplifier 616 outputs a difference signal (voltage difference) by detecting a difference between output voltages of Si-APDs 614 of the two paths. The difference signal shows a value in accordance with a magnitude of dispersion (chirp) and therefore, a dispersion of the transmission optical fiber can be detected and measured. Dispersion compensation can be carried out by controlling the tunable dispersion equalizer 606 in the controller 604 comprising PC (personal computer) by using the difference signal.

In order to measure temperature dependency of a dispersion slope of the transmission optical fiber, dispersion variation amounts of two channels in a WDM signal are monitored. The wavelength tunable filter 608 is installed before a branch to the two paths in the dispersion detection apparatus and a center wavelength thereof is set to extract a monitor channel 1( $\lambda_{mon1}$ ) by controlling a filter by the controller 604. Further, a

dispersion value in  $\lambda_{\text{mon1}}$  at a certain temperature  $T_1(^{\circ}\text{C})$  is measured and a dispersion value is stored to the controller 604. Similarly, the center wavelength of the wavelength tunable filter is set to extract a monitor  
 5 channel 2( $\lambda_{\text{mon2}}$ ), a dispersion value in  $\lambda_{\text{mon2}}$  at  $T_1(^{\circ}\text{C})$  is measured and the dispersion value is stored to the controller 604.

Next, when there is a change in environment (temperature change) to change from the temperature  $T_1(^{\circ}\text{C})$   
 10 to a certain temperature  $T_2(^{\circ}\text{C})$ , a dispersion value in  $\lambda_{\text{mon1}}$  is measured and a dispersion variation amount  $\Delta D_{\text{mon1}}$  in  $\lambda_{\text{mon1}}$  is derived from a difference from the dispersion value at temperature  $T_1(^{\circ}\text{C})$ . Similarly, measurement of a dispersion value at  $T_2(^{\circ}\text{C})$  in  $\lambda_{\text{mon2}}$  is carried out. Then,  
 15 a dispersion variation amount  $\Delta D_{\text{mon2}}$  in  $\lambda_{\text{mon2}}$  is derived from a difference between the dispersion value at temperature  $T_2(^{\circ}\text{C})$  and the dispersion value at temperature  $T_1(^{\circ}\text{C})$ .

When the dispersion slope temperature dependency of the transmission optical fiber can be approximated by a  
 20 linear line, a dispersion variation amount  $\Delta D(\lambda)$  in a certain arbitrary wavelength ( $\lambda$ ) is represented as follows and therefore, dispersion variation amounts, that is, dispersion amounts to be compensated in respective wavelength channels are known from the equation.

$$25 \quad \Delta D(\lambda) = \frac{\Delta D_{\text{mon2}} - \Delta D_{\text{mon1}}}{\lambda_{\text{mon2}} - \lambda_{\text{mon1}}} \cdot (\lambda - \lambda_{\text{mon1}}) + \Delta D_{\text{mon1}} \quad (3)$$

An optical signal transmitted through the

transmission optical fiber is branched to respective wavelength channels by an arrayed waveguide grating (AWG) 607 and inputted to the tunable dispersion equalizer 606. Further, dispersion variation amounts in accordance with  
5 respective channels derived from the above-described calculation are compensated by controlling a tunable dispersion equalizer 606 by the controller 604. The tunable dispersion equalizer 606 in which a dispersion of a chirped fiber Bragg grating is made variable by using  
10 a heater can be used. When this is illustrated, as shown by Fig. 8, by compensating a dispersion produced by a temperature change by the tunable dispersion equalizer 606 for respective channels, temperature dependency of the dispersion slope can be compensated.

15 (Fifth Embodiment)

The optical signal transmitted to the transmission optical fiber may be divided into one or more wavelength channel groups constituted by a plurality of wavelength channels by an arrayed waveguide grating (AWG). In this  
20 case in a constitution shown in Fig. 7, the optical signal transmitted through the transmission optical fiber is divided into the one or more wavelength channel groups constituted by the plurality of wavelength channels by the arrayed waveguide grading (AWG) 607 and inputted to the  
25 tunable dispersion equalizer 606. Further, dispersion variation amounts in accordance with respective wavelength channel groups derived from the

above-described calculation are compensated by controlling the tunable dispersion equalizer 606 by the controller 604.

(Sixth Embodiment)

5           In the constitution shown in Fig. 7, in place of the chirped fiber Bragg grating, a variable dispersion equalizer of a planar lightwave circuit (PLC) type which is a variable dispersion equalizer of a filter type described in (K.Takiguchi et al., "Dispersion slope  
10 equalizer for dispersion shifted fiber using a lattice-form programmable optical filter on a planar lightwave circuit," J. Lightwave Technol., vol. 16, no. 9, p. 1647 (1998)) may be used.

(Seventh Embodiment)

15           In the constitution shown in Fig. 7, as a tunable dispersion equalizer, in place of the chirped fiber Bragg grating, LOTADE (M. Jablonski et al., "Adjustable coupled two-cavity allpass filter for dispersion slope compensation of optical fibres," Electron Lett., vol. 36,  
20 no. 6, p. 511 (2000)) which is a tunable dispersion equalizer of a filter type may be used.

(Eighth Embodiment)

Fig. 9 shows an eighth embodiment of the invention.

According to the embodiment, as shown in Fig. 10,  
25 there is constructed a constitution of summarizingly compensating dispersions generated by a temperature change for all bandwidths. A tunable dispersion equalizer

by a chirped fiber Bragg grating having a wide bandwidth is used.

A tunable dispersion equalizer 806 of a dispersion slope temperature dependency compensating apparatus  
5 introduces an optical signal on the transmission optical fiber to a chirped fiber Bragg grating 803 by an optical circulator 804 and outputs the optical signal again to the transmission optical fiber. As shown in Fig. 11, a number of heaters 802 are attached in a longitudinal direction  
10 of the chirped fiber Bragg grating 803. Further, by attaching a temperature gradient in the longitudinal direction, a dispersion variation amount generated by a temperature change on the transmission optical fiber is cancelled by a dispersion variation amount having a reverse  
15 characteristic. The temperature dependency of the dispersion slope can be compensated by the method.

(Ninth Embodiment)

In the constitution shown in Fig. 9, in place of the heater of the eighth embodiment, a piezoelectric element  
20 can be used.

As shown in Fig. 12, in a tunable dispersion equalizer according to a ninth embodiment of the invention, the chirped fiber Bragg grating 803 having a wide bandwidth is attached with piezoelectric elements 1102 divided in  
25 the longitudinal direction. Further, a dispersion generated by a temperature change is canceled by a dispersion variation amount having a reverse

characteristic by changing an elongation and contraction amount of the piezoelectric element in the longitudinal direction. The temperature dependency of the dispersion slope can be compensated by the method.

5 (Tenth Embodiment)

Fig. 13 shows an optical fiber accommodation apparatus of the invention. The principle of the embodiment is that by finely controlling temperature of a periphery of a dispersion compensating fiber disposed  
10 in an optical node, a sum of influences of temperature dependencies of dispersion slopes of a transmission optical fiber and the dispersion compensating fiber in the optical node is restrained.

An optical fiber accommodation apparatus 1202 of the  
15 invention includes a temperature control circuit 1204 and contains a dispersion compensating fiber 1208 in an optical node. The transmission optical fiber is provided with a length of  $L_1(\text{km})$  and a dispersion slope temperature constant of  $\alpha_{T1}(\text{ps}/\text{nm}^2/\text{km}/\text{deg})$  and the dispersion  
20 compensating fiber in the optical fiber accommodation apparatus is provided with a length of  $L_2(\text{km})$  and a dispersion slope temperature constant of  $\alpha_{T2}(\text{ps}/\text{nm}^2/\text{km}/\text{deg})$ . When a wavelength bandwidth of an optical system in an optical transmission system is  $\Delta\lambda(\text{nm})$   
25 and a range of an allowable dispersion in the transmission system is equal to or larger than  $-\Delta D_0(\text{ps}/\text{nm})$ , however,  $\Delta D_0 > 0$ ) and equal to or smaller than  $\Delta D_0$  and a temperature

change throughout a year to which the transmission optical fiber is subjected is  $\Delta T_1(\text{deg})$ , a temperature change  $\Delta T_2(\text{deg})$  to which the dispersion compensating fiber 1208 is subjected is set to satisfy the following equation by  
5 using the temperature control circuit 1204.

$$|\alpha_{T1} \cdot L_1 \cdot \Delta T_1 + \alpha_{T2} \cdot L_2 \cdot \Delta T_2| \cdot \Delta \lambda \leq \Delta D_0 \quad (4)$$

Thereby, the influences of the temperature dependencies of the dispersion slopes of the transmission optical fiber 1206 and the dispersion compensating fiber  
10 1208 can be restrained.

The present invention has been described in detail with respect to preferred embodiments, and it will now be apparent from the foregoing to those skilled in the art that changes and modifications may be made without  
15 departing from the invention in its broader aspect, and it is the intention, therefore, in the apparent claims to cover all such changes and modifications as fall within the true spirit of the invention.